Representation of Carbon Capture and Storage Technologies in Energy and Economic Models and Next Steps

**Second National Conference on
Carbon Sequestration
May 5-8, 2003**

**Jim Dooley, Jae Edmonds,
Bob Dahowski & Marshall Wise
Joint Global Change Research Institute**

Battelle

The Potential Role for Carbon Capture and Sequestration

- Carbon capture and sequestration (CCS) could be one of the most important levers we have to address climate change.

- Over the course of the century, CCS technologies could account for 30% or more of all climate mitigation beyond "business as usual" technology improvements.

- CCS technologies if widely deployed can reduce the cost of stabilization by one third or more.

- CCS technologies will likely be deployed on a massive scale around the globe.

- CCS deployment will start before the middle of the century.

Outline

- ▶ Two major categories of energy and economic models, with strengths and weaknesses:

    - Top Down Energy and Economic Models

    - Bottom Up Energy and Economic Models

- ▪ The evolution of this technology as a function of time is currently not well understood yet this is a key for understanding what the successful development and deployment of cost-effective CO_2 capture and sequestration will look like.

- ▪ Merging top-down and bottom up modeling frameworks will be a key to understanding the cost implications of technology development.

Battelle

A Partial List of the Growing Number of Energy and Economic Models that Explicitly Incorporate CCS

- EPPA – Massachusetts Institute of Technology
- AIM - National Institute for Environmental Studies
- SGM – Pacific Northwest National Laboratory
- MiniCAM – Pacific Northwest National Laboratory
- New Earth 21 - RITE
- GRAPE – Science University of Tokyo
- MESSAGE – IIASA
- MARKAL – International Energy Agency
- NEMS- US Department of Energy
- Dynamic Energy Systems Model - Carnegie Mellon University
- CO2-GIS – Battelle Memorial Institute

Top Down Energy And Economic Models: Common Attributes

- Tend to be general and partial equilibrium models

- Focus on integrating <u>all</u> aspects of the economy; particular focus is on market and economy-wide feedbacks and substitutions

- Global coverage with (typically) a dozen or more sub regions

- Top down models are remarkably complex in certain ways but in other ways they these models make use of very aggregate descriptions of technological systems.

Top Down Energy And Economic Models: Common Attributes

- Particularly useful in examining
  - Competition amongst a number of competing climate change abatement options.
  - Technology competition against a consistent economic background.
  - Technology evolution over the long term (e.g., 50-100 years.)
  - Technology adoption under varying future economic, demographic and emission mitigation scenarios.

- Assumptions about *future* technological progress are very important in driving results.

Example: Technology Competition for the Global Provision Of Electricity Under 550 ppmv WRE Constraint
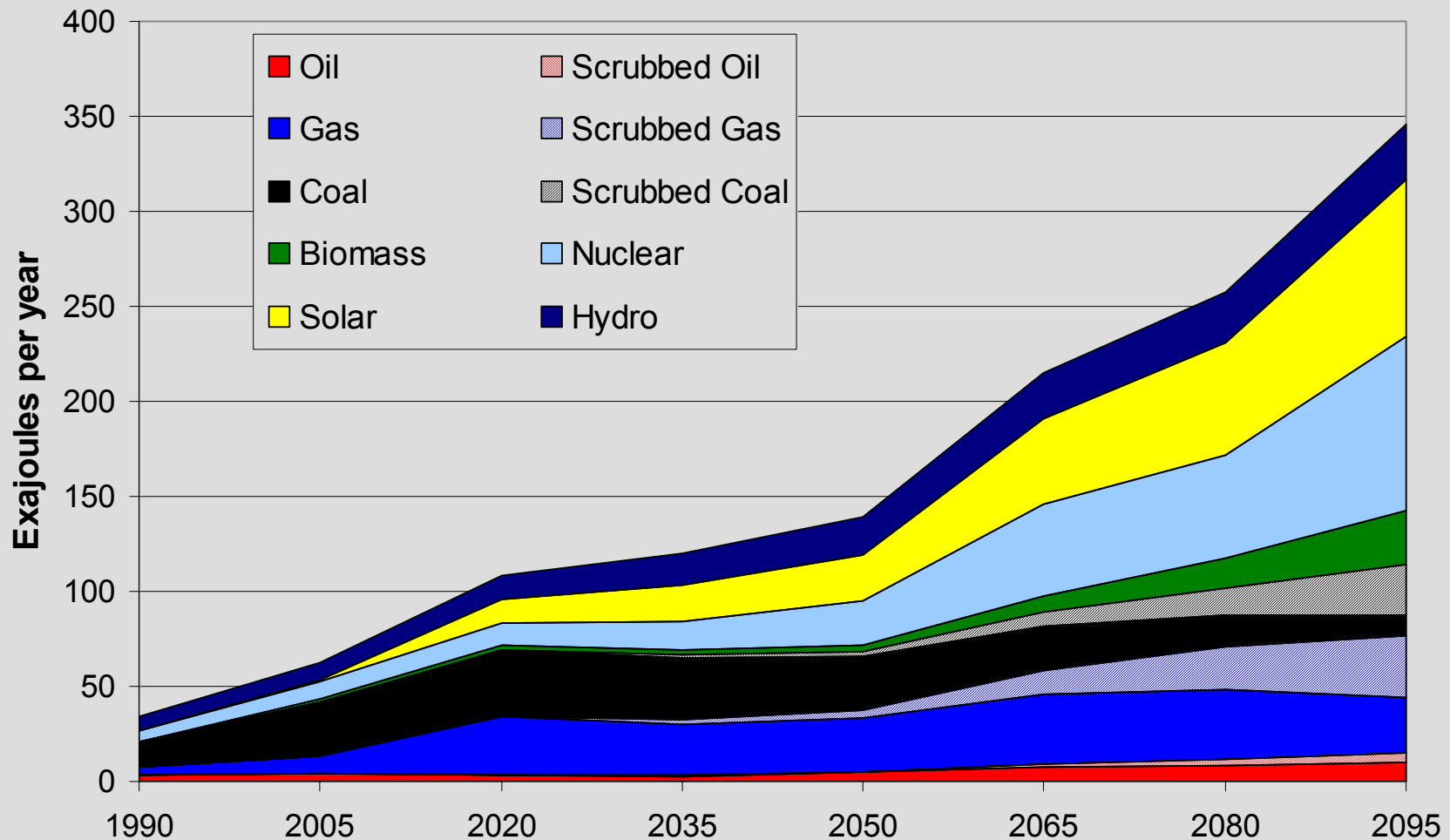
# Representation of CCS Technologies Within the Minicam

	Coal	Oil and Gas
Energy Penalty for Carbon Capture [a]	37% declining to 9%	24% declining to 10%
Additional Investment Costs for Capture System [b]	54% declining to 33%	54% declining to 33%
Transport and sequestration Cost [c]	$15/tonne of C	$15/tonne of C
Efficiency of Capture [b]	90%	90%

Sources: [a] Herzog et al., 1997. [b] Gottlicher and Pruschek, 1997.
[c] Freund and Ormerod, 1997.

Over time, technological progress assumed to take place in the "capture" aspect of system.

Battelle

Resulting Cost Trajectory As a Function of Time for CCS For The Electric Power Sector

Battelle
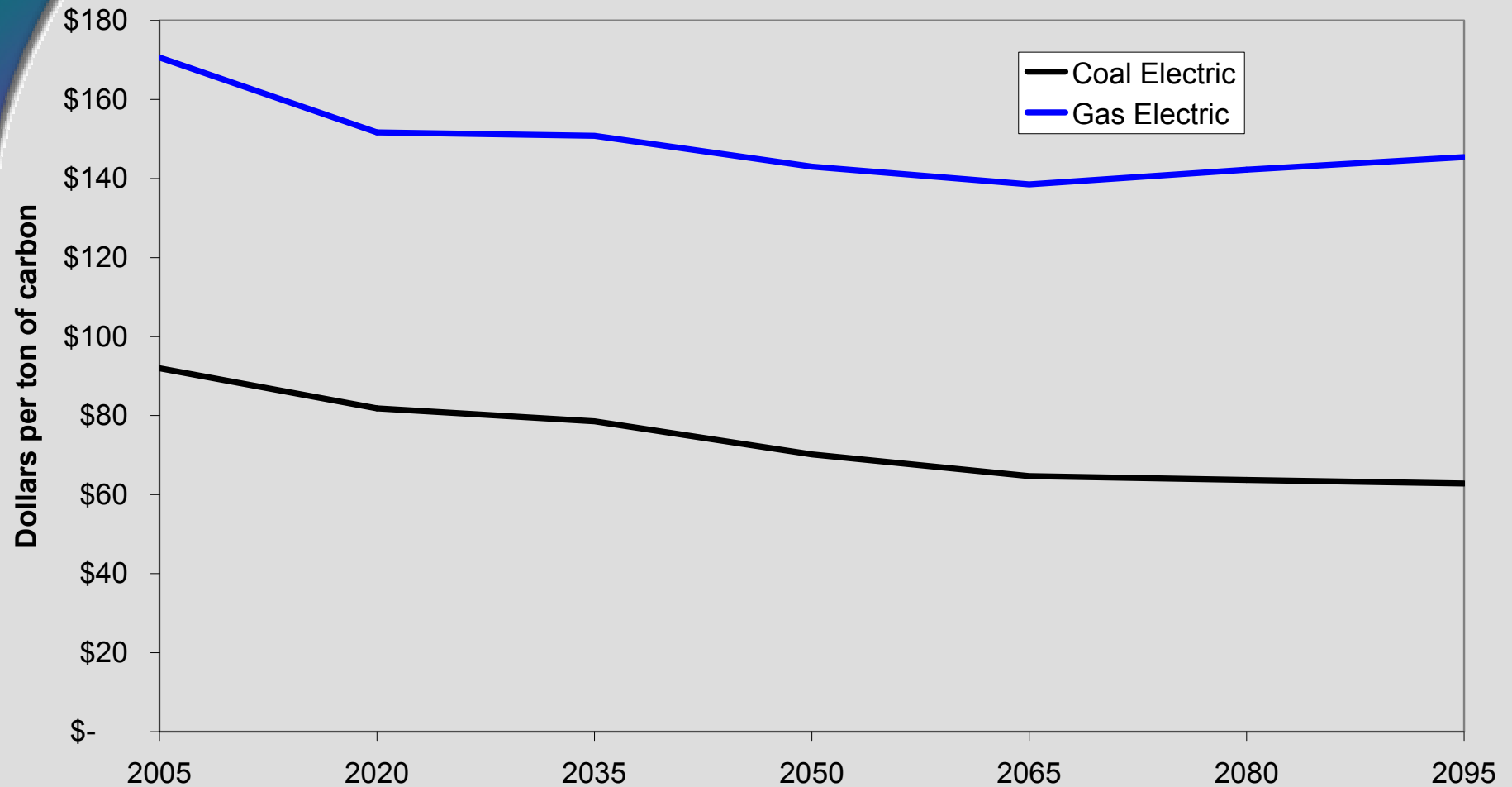
Are Sequestration & Transport Costs Really Constant?

▶ This is a very important assumption and an assumption that needs to be better understood.

▶ Constant sequestration and transport costs implies that CO_2 sequestration reservoirs are:

- evenly distributed across the globe
- homogeneous, and
- are infinite (or not meaningfully constrained).

Bottom-Up Energy and Economic Models: Common Attributes

▶ For example, linear programming / optimization models.

▶ Modeling of the economy and demand for energy are sometimes exogenously specified.

▶ Tend to be more detailed and more focused in their technology characterization less so in their depiction of the overall economy.

▶ Tend to be focused on a specific region (e.g., the US) or only on a given small set of technologies (e.g., the electric power sector) or both (e.g., electric power sector in the North Eastern USA).

Bottom Up: An Attempt To Model Real World Assets

Plant Name	Barry
GenCode	5
County	Mobile
State	AL
Type	Utility
Primary Fuel	Coal
Primemover	Steam Turbine
Nameplate Capacity, MW	789
Summer Capability, MW	768
Capacity Factor	0.642
Vintage	1971
Cogen?	No
SO_2 Controls?	No
NO_x Controls?	Yes
1999 CO_2 Emissions, tons	5,496,151
Utility	Alabama Power Co.
Parent Company	The Southern Company
Latitude	31.0069
Longitude	-88.0103

FIELD	Anton Irish
TYPE	CO2 miscible
OPERATOR	Altura
STATE	Tex.
COUNTY	Hale
START_DATE	4/1/1997
AREA__ACRE	1600
Z_PROD__WE	82
Z_INJ__WEL	40
PAY_ZONE	Clearfork
FORMATION	Dolomite
POROSITY__	7
PERMEABILI	5
DEPTH__FT_	5900
API_GRAVIT	28
VISCOSITY_	2.7
TEMP___F	115
PREVIOUS_P	Primary, Waterflood
SATUR____S	
SATUR____E	
PROJECT_MA	Just Started
TOTAL_PROD	7800
ENHANCED_P	4500
PROJECT_EV	Successful
PROFIT_	Yes
PROJECT_SC	Field Wide
DD_LON	-102.063889
DD_LAT	33.839444
SOURCE	GNIS - oilfield
CO2_TYPE	Natural
CO2_SOURCE	Bravo Dome

Variables in a Bottom Up Model's Representation of CCS System

► Cost of capture:
  - Model real-world system capital costs
 - Model real-world energy and O&M costs

► Cost of transport:
  - Actual pipeline distances
  - Ability to factor in items like booster pumps for long pipelines
  - Pipeline sized to handle specific flow amounts

► Cost of sequestration:
  - Number of injection wells should be based upon CO_2 flow from source number of wells needed dependent on individual formation/reservoir characteristics
  - "Net cost of sequestration" calculation heavily dependent upon there being nearby "value added reservoirs"

All of these are variable and all are dependent upon characteristics of sources <u>and</u> sinks.

This is <u>not</u> a homogenous set of opportunities for CCS deployment.
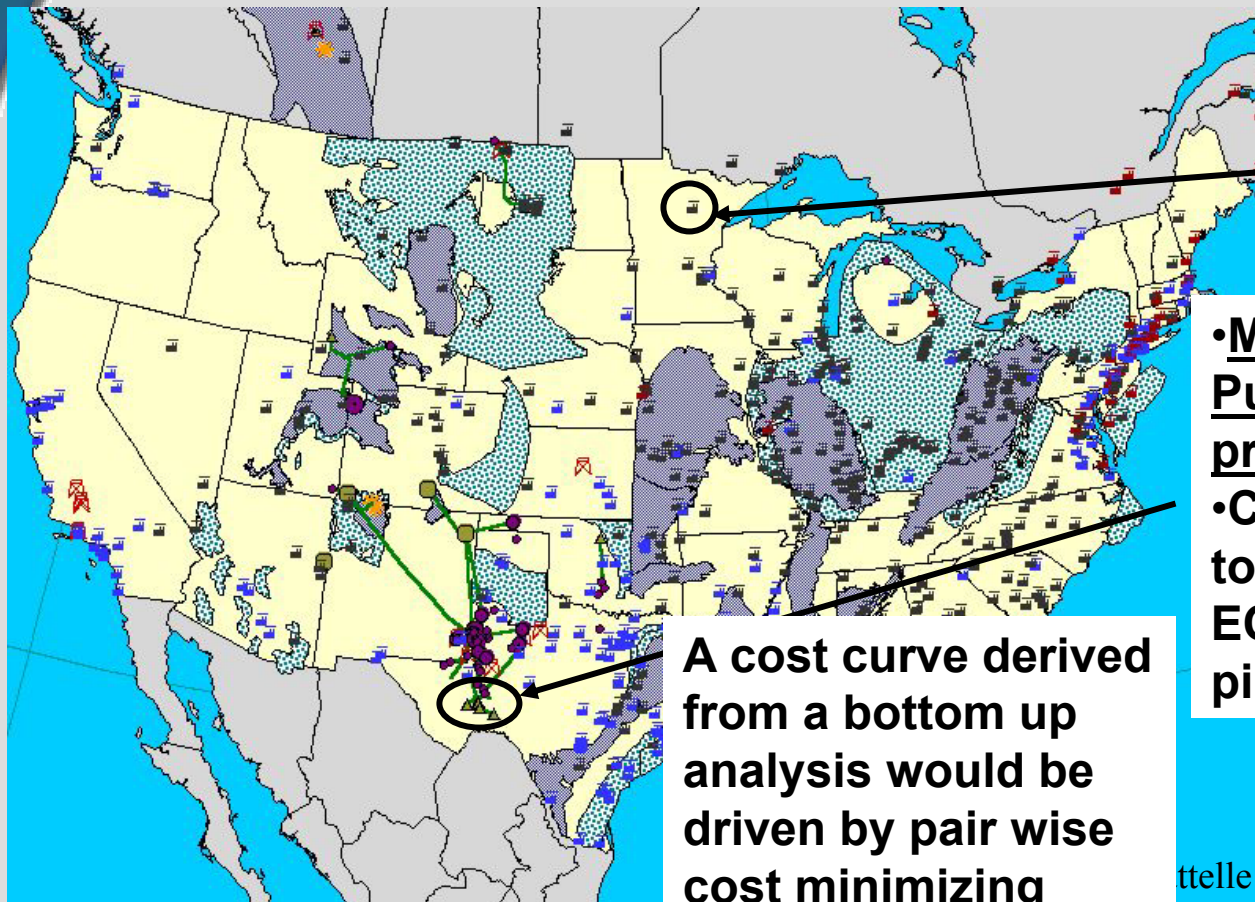
- **<u>Clay Boswell Plant</u>**
- **923MW coal power Vintage: 1973-1980**
- **6M tons of CO_2**
- **Deep saline formation 290 miles to the West.**

- **<u>Mitchell, Terrell, Warren & Pucket natural gas processing plants</u>**
- **Currently sell a few million tons of CO_2 to existing EOR projects via existing pipelines**

formations

- **19 major coal basins**

- **70 CO_2-driven EOR projects**

A cost curve derived from a bottom up analysis would be driven by pair wise cost minimizing decisions at each point in time.
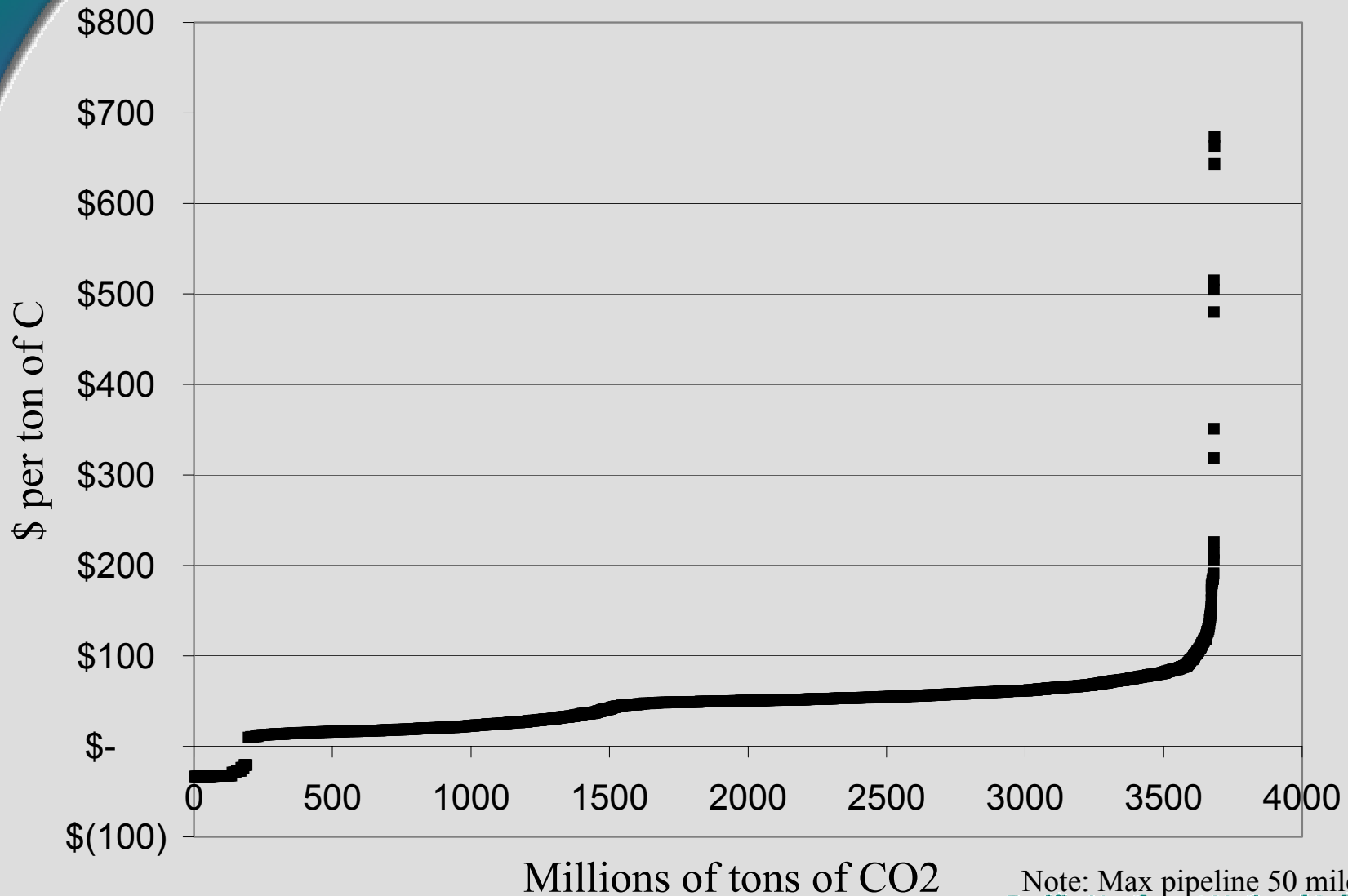
A Pair Wise "Bottom Up" Deployment Schedule /Cost Curve For CCS

Millions of tons of CO2

Note: Max pipeline 50 miles.

Summary: Points of Agreement

▶ Both types of energy and economic models seem to agree on a number of broad principles:

- Relatively small niche market for CCS technologies in the absence of a CO_2 emissions mandate

- Ultimate deployment of this class of technologies could be massive

- Electricity produced from coal with CCS likely cheaper than capture from NGCC with CCS.

  - CCS technologies will increase deployment as the technology improves
  - CCS technologies' deployment accelerates as carbon permit prices rise

Legend:
- Oil
- Gas
- Coal
- Biomass
- Solar
- Scrubbed Oil
- Scrubbed Gas
- Scrubbed Coal
- Nuclear
- Hydro

Y-axis: Exajoules per year (0–400)
X-axis: 1990, 2005, 2020, 2035, 2050, 2065, 2080, 2095
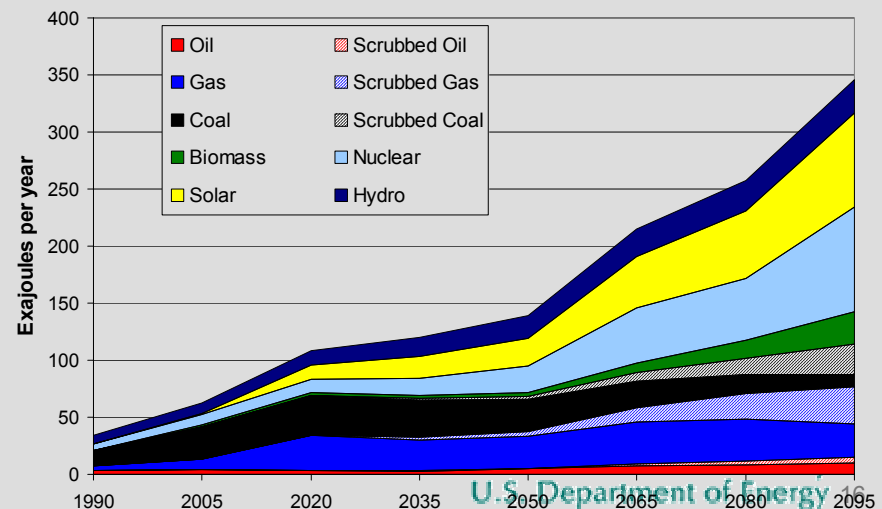
Summary: Points of Disagreement

▶ What is the cost of electricity produced by CCS systems?

▶ What is the carbon price that triggers the commercial deployment of CCS technologies?

▶ What is the global, regional, and local CO_2 sequestration capacity of various reservoirs?

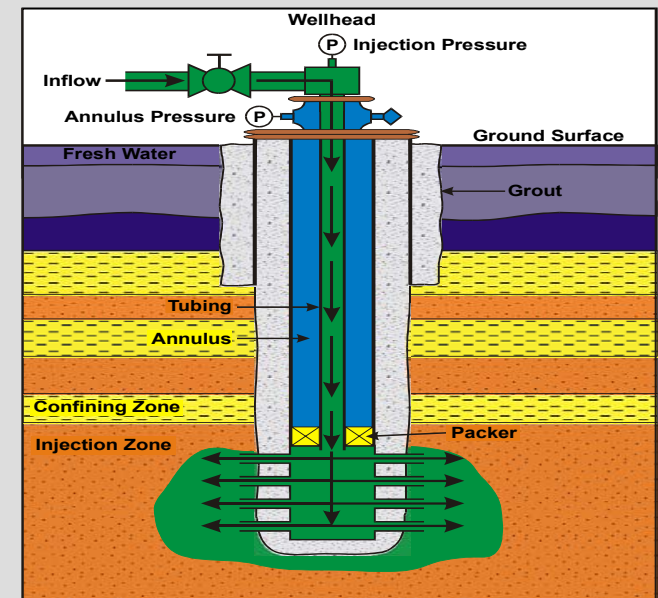▶ What is the ultimate deployment potential for CCS technologies?

Research Needs: Understanding CCS Deployment Beyond Electric Power Sector

- ▶ As noted earlier, much of the modeling of CCS is focused on the utilization of these technologies by the electric power sector.

- ▶ However, in order to stabilize CO_2 concentrations, all CO_2 emissions need to be controlled.

- ■ Much more work needs to be done in exploring the the dynamics of CO_2 abatement and the possible use of CCS by these other industrial sectors.

|	Number of Facilities in US	CO$_2$ Flue Gas Purity
Ammonia	38	8-99%
Cement	121	20-30%
Ethylene	39	10-15%
Ethylene Oxide	13	100%
Natural Gas Processing	584	1-99%
Hydrogen Production	87	8-99%
Iron and Steel	136	15%
Refineries	156	3-13%

Research Needs: Injection Rates

▶ At Sleipner, one injection well handles approximately 1m tons of CO_2 / year. Is this a typical formation?

▶ How many injection wells are needed to handle 1m tons of CO_2 in a typical deep saline formation? In a typical coal seam?

▶ Does the number of wells needed for injection into a given formation vary with time?

▶ How closely can multiple injection wells be placed together?

■ How long can any given injection well operate?

■ Is there a (serious?) mismatch between the expected lifetime of a power plant and an injection field wells' capacity?

Labels in diagram: Wellhead, (P) Injection Pressure, Inflow, Annulus Pressure (P), Ground Surface, Fresh Water, Grout, Tubing, Annulus, Confining Zone, Injection Zone, Packer

Research Needs: "Net Transport Distance"

► Of those models that attempt to address transport distance as a variable, they generally tend to make the simple assumption of one-to-one pairing of source and sink via a dedicated pipeline.

► Possible determinants of whether and when CO_2 networks will evolve:

– The social acceptance of CO_2 pipelines

– The potential magnitude and demand for sequestration in a given region.

– The nature of capital stock within a region and how fast it might turn over.

Battelle
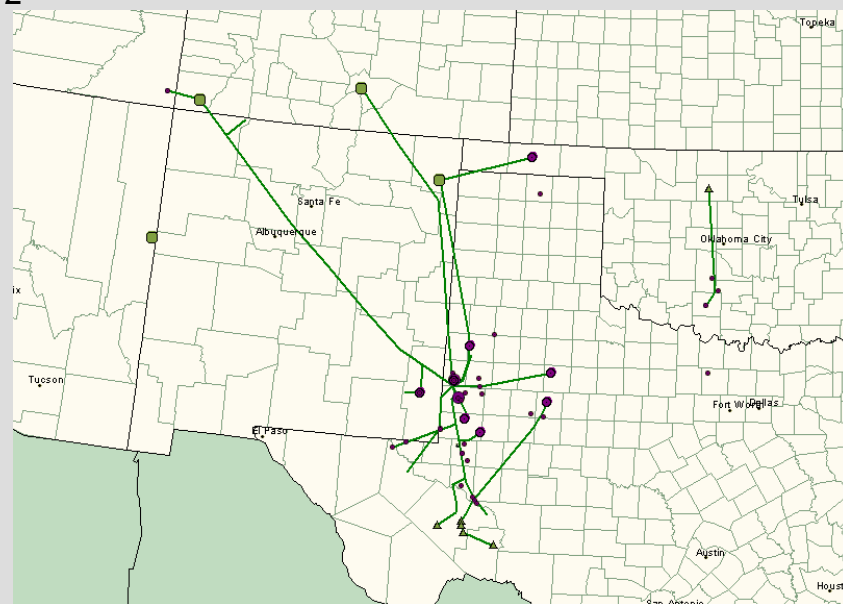
Research Needs: Value Added Formations

▶ What is the supply of "value added formations" and their capacity to accept CO_2 as a function of time?

▶ Are these value added formations located near current or <u>future</u> major CO_2 point sources?

▶ Will the amount of oil or CH_4 produced by CO_2-driven EOR and ECBM be so large that it will affect the price paid for oil and natural gas?

▶ If value added formations are located near a large concentration of CO_2 point sources and supply of CO_2 outstrips demand, what happens to the price of CO_2?

▶ Who gets these rents if any?

Research Needs: What is the universe of possible CO_2 sinks and their location?

© 2002 Battelle Memorial Institute
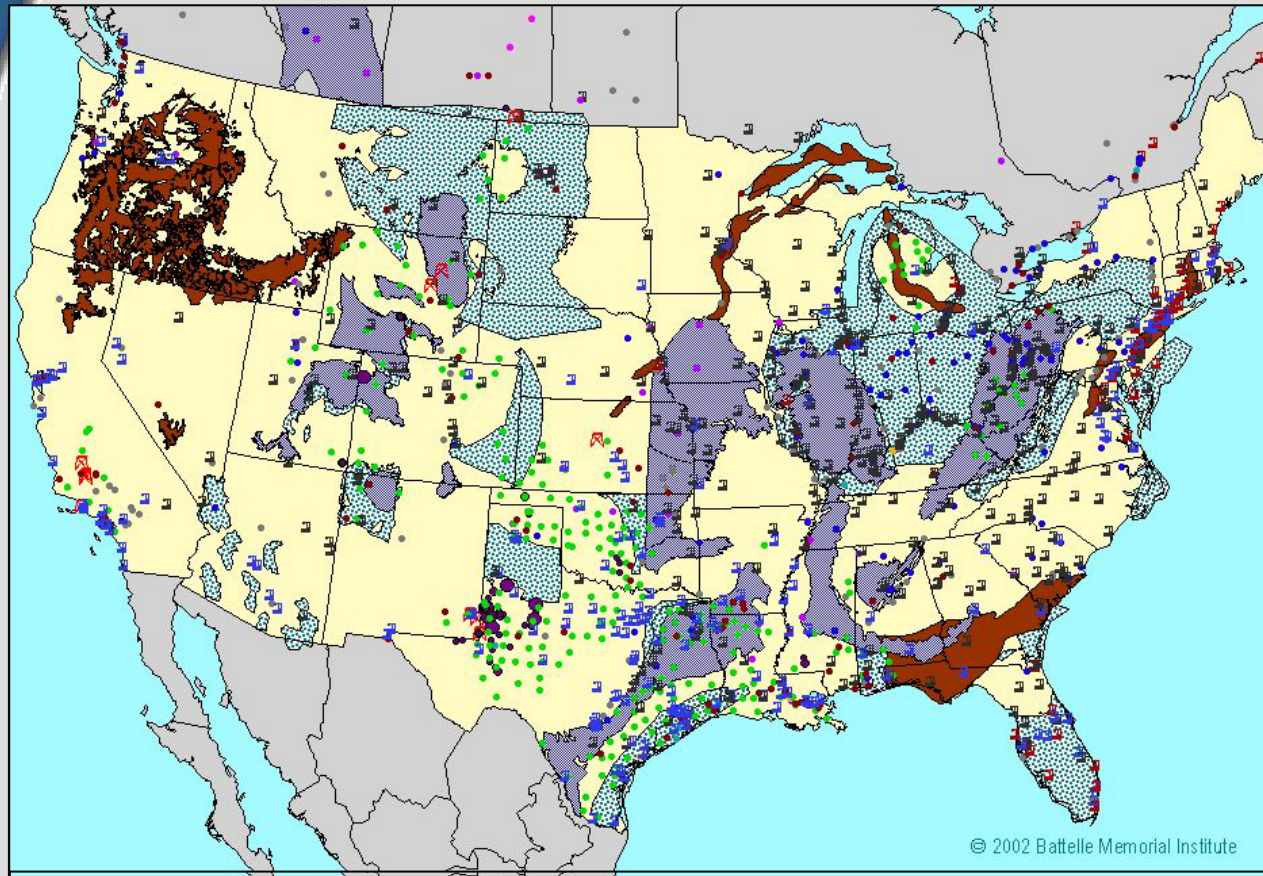
Enhanced Oil Recovery (EOR): 70 Projects, 190,000 bbl/d enhanced production
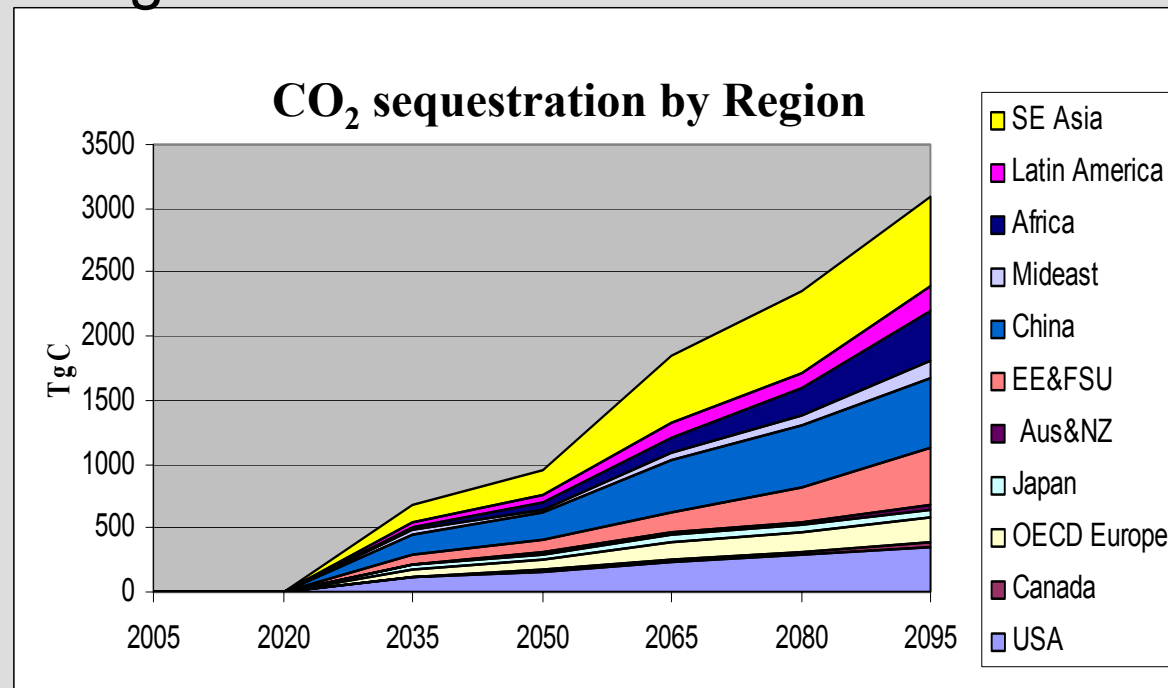
Deep Coal Basins: 21 basins, 230 TCF technically recoverable CBM reserves

Priority Deep Saline Aquifers: 21 initial formations selected

Deep Basalt Formations: Handful of formations identified

Battelle

Research Needs: Distribution of CO_2 Sequestration Reservoirs Across the Globe

▶ Over time, the OECD region is likely to be a minor player in global CO_2 capture and sequestration utilization.

▶ The growth in emissions will be outside of the OECD, therefore these non-Annex 1 regions are a likely major market for CCS technologies.

▶ Where are the CO_2 sequestration reservoirs in India, China, Russia, and Latin America? And who should pay so that we can know this now rather than later?

CO_2 sequestration by Region

TgC

3500
3000
2500
2000
1500
1000
500
0

2005 2020 2035 2050 2065 2080 2095

Legend:
- SE Asia
- Latin America
- Africa
- Mideast
- China
- EE&FSU
- Aus&NZ
- Japan
- OECD Europe
- Canada
- USA

Battelle

Research Needs: Other Examples

► Monitoring, Verification, and Ancillary Costs *Over Time*

► Rental value of carbon (e.g., what is the value of less than permanent retention?)

► How do CCS technologies facilitate the attainment of non-climate air pollution control?

► What role do other proposed systems play:

- mineralization

- carbon black

- free air scrubbing?

► Ocean sequestration

- Injection into upper well mixed layer

- Pooling / deep injection, clathrates

Field Experiments And Relevantly Scaled Demonstrations Are Needed To Narrow Key Uncertainties
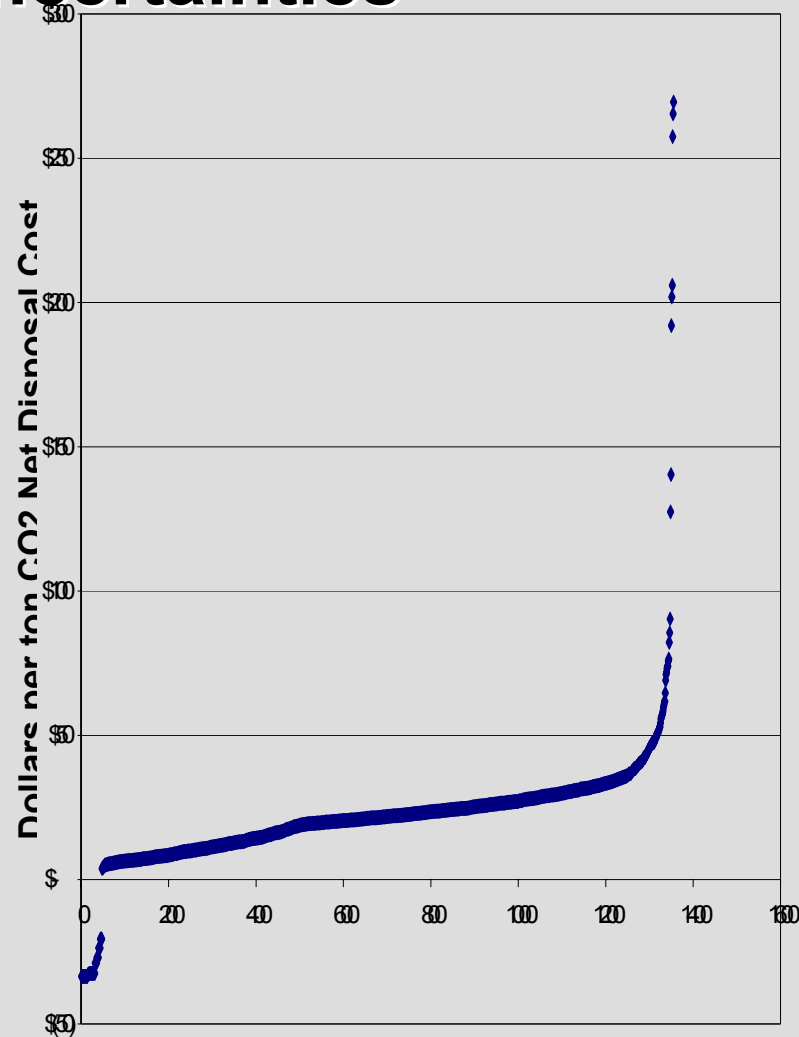
Cost of Capture as a Function of Time

Cost of Transport as a Function of Time

Cost of sequestration as a Function of Time

?

?
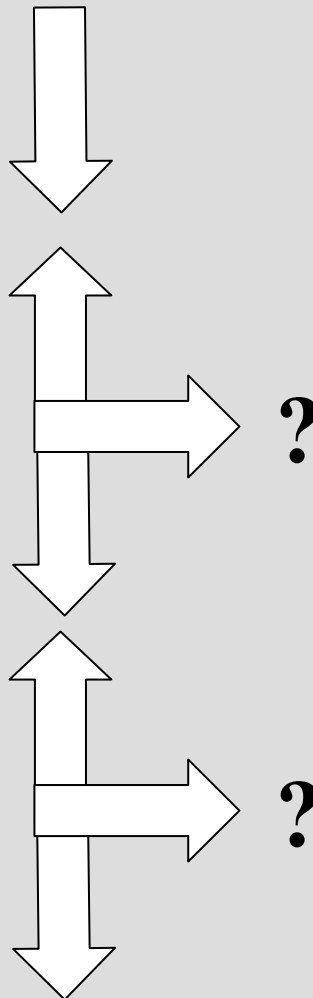
Conclusions

- ► "Top down" and "bottom up" models are very useful tools in understanding many facets of the deployment of CCS systems in a greenhouse gas constrained world.

- ► There is much to be done to improve the models and this work is underway in many places.

- ► The models, however, will not likely yield *significant* new revelations absent data from field experiments.

  - ■ Where are CO_2 sequestration reservoirs and what is their storage potential (per day, per year and cumulative potential over time) at a basin scale?

  - ■ What is the <u>future</u> cost of CO_2 "capture systems," broadly defined?

A Fuller Version of this Paper and Its Analysis Can Be Found At

IPCC Workshop for Carbon Capture and Storage 2002
Regina, Canada November 2002
ftp://ftp.ecn.nl/pub/www/library/conf/ipcc02/ccs02-12.pdf